Biological Information on Juvenile Salmon
Related to Operation of McNary Turbines Outside the 1% Efficiency Limit

Abstract

NOAA Fisheries' 2000 Biological Opinion (BiOp) for the Federal Columbia River Power System calls for operating turbines within 1% range of best peak efficiency (1% limit) during the juvenile fish outmigration. Bonneville Power Administration (BPA) has requested that this criterion be removed at McNary Dam. This report has been prepared to evaluate the potential effects of the proposed operation for spring of 2004 on anadromous salmonids, particularly those listed for protection under the Endangered Species Act (ESA).

In 2004, operating McNary turbines above the 1% limit will result in more flow going to the powerhouse and decrease the amount of involuntary spill that would otherwise occur by about 2.5% of the total springtime project flows. This change in turbine operation will result in an increased economic benefit. However, this also means that flows will increase through the turbine intakes, past the extended-length fish diversion screens (ESBS) and into the gatewells and that the tailrace environment will be altered, potentially affecting fish egress. These changes will influence juvenile fish passage routes and affect their overall survival at McNary Dam.

Based on our evaluation, we estimate that operating McNary turbines above the 1% limit in the spring of 2004 may decrease the overall project average survival rate by less than 0.2% for yearling Chinook and steelhead. This lower survival rate is attributable to the decreased involuntary spill, because the change in flow distribution will result in about 3.6% of the juvenile fish migrants to be redistributed from the spillway to the powerhouse. Although the impacts to the fish redistributed to the powerhouse under the higher turbine discharge are uncertain, the greatest impact is expected to occur in the gatewells. Therefore, it is necessary to have a comprehensive in-season monitoring plan sufficient to detect increased fish injury in the gatewell environment, thus allowing for in-season management decisions (i.e., reinstate the 1% limit) to minimize potential adverse effects. Absent an adequate gatewell-monitoring program, fish survival may be even lower.

1. Proposed Action

The BPA has proposed eliminating the 1% turbine limit at McNary Dam. This assessment covers the 2004 spring fish migration season (April to approximately mid to late June). The origin of the operating limit is based on a review of fish survival studies under different turbine geometries and operations (Bell 1981). From Bell's analysis, a hypothesis evolved that fish survival and turbine efficiency are directly related. This hypothesis led to development of the 1% limit turbine operating guidelines for the FCRPS projects that have been included in the Corps' Fish Passage Plan (FPP) since 1993 and that are part of NOAA Fisheries' 2000 FCRPS BiOp. When BPA evaluated Bell's (1981) review and the results of a recent biological study at McNary Dam, they concluded that operating McNary turbines above the 1% limit may not be different from the existing conditions and might provide a higher fish survival (Skalski, *et al*., 2002). This report does not address the BPA proposal to change summer operations it will be covered in a separate analysis at such time that BPA requests.

2. ESA-Listed Fish

Four evolutionarily significant units (ESU) of ESA-listed salmon from the Snake River (sockeye, spring/summer Chinook, fall Chinook and steelhead) and three ESUs from the Columbia River (Upper Columbia River spring Chinook and upper and middle Columbia River steelhead) migrate past McNary Dam as juveniles and adults. Descriptions of these ESUs, including run timing and life histories, are discussed in the NOAA Fisheries' 2000 BiOp. This report des not address summer operations, therefore, ESA listed fall Chinook are not included in this assessment.

3. Hydraulic Effects of the Proposed Action

Under the existing 1% limit, turbine discharge varies from 7,800 cfs to approximately 12,400 cfs, depending on total project head, and the powerhouse hydraulic capacity is about 170,000 cfs. The BiOp calls for nighttime spring spill (1800 to 0600 hours) to improve juvenile fish passage. Spill volume is controlled by the total dissolved gas (TDG) with the maximum allowable spill not to exceed state water quality standards for TDG ("gas cap"). Both Oregon and Washington have issued waivers to their water quality standards that allow TDG levels (measured in the tailrace) of up to 120% of saturation. Under the 50-year average river flows the spill volume that meets these conditions ranges from approximately 150,000 to 180,000 cfs. Because the 50-year average spring flows passing McNary Dam range between 260,000 to 280,000 cfs there are extended periods when flows exceed the powerhouse capacity and voluntary spill gas cap, thereby forcing daytime involuntary spill. The frequency of involuntary spill is further reduced by the current operation that uses the flexibility of forebay to pond water during the day for release at night. This operation eliminates involuntary spill for river flows up to 230,000 cfs.

This year (spring 2004) the April final flow forecast (April – June) predicts river flows will be lower than average. To determine the effect of the forecast on flows at McNary Dam the Weather Service's model, ensemble stream flow predictor (ESP), was used to model similar historic weather patterns to the current day's conditions. Based on the modeling of the ESP (1-4) runs, RCC estimated the average springtime flows expected at McNary to be approximately 185,000 cfs (Table 1).

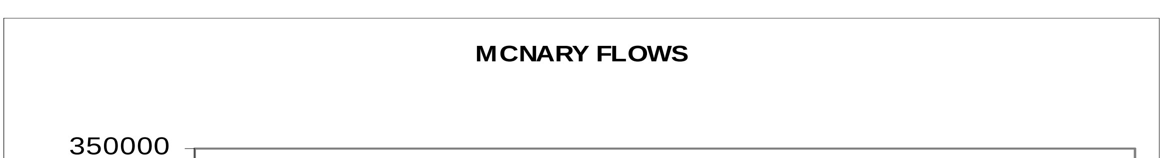
Table 1. Estimated Spring Flows at McNary 2004 Based on the ESP Modeling Runs.

McNary

			Spill Assumed from 12 April - 30 June		
	Apr - Aug Runoff Volume at The Dalles	April 10 - 30 June Average Regulated Flow (kcfs)	Vol Voluntary Spill (kaf)	Vol of Involuntary Spill within 1% Turbine Limit (kaf)	Vol of Involuntary Spill outside 1% Turbine Limit (kaf)
ESP 1	79.0 MAF	187,600	8585	633	0
ESP 2	78.1 MAF	181,000	8823	267	0
ESP 3	77.2 MAF	186,400	8115	976	6
ESP 4	76.8 MAF	187,700	8564	556	0
Average	78.0 MAF	185,675	8522	608	1
STP		169,400	8523	0	0

Under the average ESP forecast, flows are expected to exceed 230,000 cfs approximately 20% of the spring thereby resulting in no involuntary spill at McNary 80% of the springtime. Flows estimated between 230,000-260,000 cfs are expected 17.4% of the time and 260,000-280,000 cfs 2.5 % of the time (Figure 1).

The proposed turbine operation will allow turbine discharges to increase up to a maximum of 16,400 cfs. In 2004 one unit is anticipated to be unavailable for the duration of the spring season and another unit will be operated at 12,400 cfs for baseline monitoring proposed for the duration of the operation. This will result in a total powerhouse discharge to about 209,000 cfs. This change in turbine discharge will reduce the percentage of daytime involuntary spill. Nighttime BiOp spill operations ranging (140,000 to 180,000 cfs) will remain in effect. At the higher turbine discharge, with estimated 2004 spring flows passing McNary Dam, involuntary day spill will be reduced by an average of 2.5% over the spring season (Table 4).
Figure 1. Range of 2004 Forecasted River Flows (ESP Runs) at McNary (provided by RCC)



4. Biological Effects

An increase in turbine discharge affects the overall project hydraulics both upstream and downstream of the dam. Higher discharges through the turbines will decrease the amount of involuntary spill, increase flows past the extended-length fish diversion screens and into the gatewells, and alter the tailrace environment. These changes will influence juvenile fish passage routes and affect their overall survival at McNary Dam.

a. Spill and Fish Passage Distribution

The proposed increase in turbine discharge will redistribute flows across the project and reduce the involuntary spill volume. Assuming that migrating fish follow flows, they will also be redistributed and, therefore, more would redistribute to the powerhouse and pass either through the turbines or the juvenile fish bypass system. In the spring, approximately 2.5% of the total springtime project flow will be redirected through the turbines. As the percentage of the river spilled changes, the efficiency of spilled flow in passing fish changes (ratio of fish passed to spill; spill effectiveness). Using for each range of flows forecasted for 2004 (Table 4) the estimated change in involuntary spill (Table 2) and the spill effectiveness ratios developed by NOAA Fisheries (Table 3), an average of about 3.6% (weighted average of percentage of flow) of the spring migrants will be redistributed from the spillway to the powerhouse. Fish diverted from involuntary spill may experience longer forebay residence times and increased exposure to predators. However, it is unknown what impact forebay delay has on project survival at McNary.

Table 2. Estimated Involuntary Spill at McNary

Existing Condition	Low Flows	Medium Flows	High Flows
Day	**230,000 cfs**	**260,000 cfs**	**280000 cfs**
Total River Flow	161,000	209,000	219,000
PH capacity @12,400	161,000	161,000	161,000
Involuntary Spill Level	0	48,000	58,000
Involuntary Spill % of Total Flow	0.0%	23.0%	26.5%
Daytime Spill Effectiveness*	0.0%	36.0%	45.0%
Night			
Total River Flow	299,000	311,000	341,000
PH capacity @12,400	159,000	161,000	161,000
Voluntary Spill Level	140,000	150,000	180,000
Voluntary Spill % of Total Flow	46.8%	48.2%	52.8%
Night Spill Effectiveness*	60.0%	60.0%	60.0%
Night time to the Gas Cap Spill Level	140,000	150,000	180,000
Voluntary Night Spill % of Total Flow	46.8%	48.2%	52.8%
Nighttime Spill Effectiveness 1:1	46.8%	48.2%	52.8%
Increased Turbine Discharge	**Low Flows**	**Medium Flows**	**High Flows**
Day			
Total River Flow	209,000	209,000	209,000
PH capacity @16,400	209,000	209,000	209,000
Involuntary Spill Level	0	0	0
Involuntary Spill % of Total Flow	0.0%	0.0%	0.0%
Daytime Spill Effectiveness*	0.0%	0.0%	0.0%
Night			
Total River Flow	251,000	311,000	351,000
PH capacity @16,400	111,000	161,000	171,000
Voluntary Spill Level	140,000	150,000	180,000
Night time to the Gas Cap Spill Level	140,000	150,000	180,000
Voluntary Night Spill % of Total Flow	55.8%	48.2%	51.3%
Nighttime Spill Effectiveness 1:1	55.8%	48.2%	51.3%
Estimated Change in SPE			
Daytime 12 hr Spill (involuntary)	0.0%	36.0%	45.0%
24 Hour Spill (voluntary and involuntary)	0.0%	18.0%	22.5%

Table 3. Daytime Spill Effectiveness Ratios (Provided by NMFS).

Spill Percentage of Total Flow	Spill Passage Efficiencies	Ratio
10%	10%	1:1
12%	15%	1.25:1
15%	21%	1.4:1
18%	29%	1.6:1
20%	36%	1.8:1
25%	45%	1.8:1
30%	54%	1.8:1
35%	58%	1.65:1
40%	60%	1.5:1

Table 4. Percent Duration of Range of Forecasted Flows for Spring at McNary 2004.

Range of Flows at McNary	Expected Duration (days)	Percent of 2004 Spring Season	Change in Percent Involuntary Spill
185 kcfs to 230 kcfs	277	80%	0%
230 kcfs to 260 kcfs	60	17.5%	-11.2%
260 kcfs to 280 kcfs	7	2.5%	-24.8%
Weighted Mean			-2.5%

b. Fish Guidance Efficiency (FGE)
The FGE is influenced by turbine discharge and vertical distribution of fish as they approach the turbine intakes. A change in turbine operation may alter the intercept point of the fish and, therefore, the number that will be guided into the bypass system. Under existing operations, FGE for yearling Chinook and steelhead is about 87% (Route Specific Survival Estimates compiled by the 2003 Joint Data Review Team and NMFS, personal communication). This means that about 13% of the yearling Chinook steelhead will pass under the extended-length fish screens and through the turbines. It is not known how the proposed change in the turbine discharge will affect FGE. Conversely, a change in FGE may result in a larger percentage of the spring out migration passing through the bypass system to the river. While unresolved, the contribution of bypass at McNary on multiple-bypass delayed mortality may result in decreased system survival for juvenile migrants.

c. Gatewell Environment
Increased flow into the turbine intakes will cause more flow to be intercepted by the extended-length screens and be diverted up into the gatewells. This will increase water velocities along the screen surfaces and through the mesh as well as increase turbulence in the gatewells and increase velocities through the vertical barrier screens (VBSs). These hydraulic changes at the intake screens and in the gatewell have the potential to affect a high proportion of fish passing McNary project. Most fish entering the turbine intakes will be diverted by the extended-length screens into the gatewells where they will pass through orifices to the juvenile fish facility to be returned to the river.

- **Impingement on Intake Screens:** When the turbine units are operating at a higher discharge (16,400 cfs), the velocities passing through the screens are expected to change from approximately 1.9 fps to 2.6 fps. This velocity approaches NOAA Fisheries recommended maximum velocity through screens of 2.75 fps. Higher velocity through the screens will increase the likelihood that weaker (diseased and stressed) and smaller fish (subyearling smolts, sockeye and fry) will come into contact with or be impinged on the screens before entering the gatewells. Presently there is no direct method to measure effects of higher velocities through the extended-length screens on fish at McNary. An in-season monitoring plan to detect increased fish injury in the gatewell environment will allow for in-season management decisions to minimize potential adverse effects.

- **Turbulence:** Data from hydraulic model studies indicate that gatewell turbulence increases with increased turbine flows. High levels of turbulence have the potential to physically injure and physiologically stress fish. Fish spending time in gatewells with higher turbulence levels may fatigue and/or be injured. Fatigue and injury often have latent effects on fish health that may alter their survival rate.

Yearling Chinook descaling evaluations conducted during fish division screen development have provided mixed results for higher turbine flow conditions. Test data from different diversion screen configurations in 1992 showed that descaling differed under high and lower flows but not significantly (McComas *et al*, 1992). However, results of a 1997 study to assess methods of reducing gatewell turbulence indicated that yearling Chinook descaling increased significantly with higher turbine discharges (Brege, *et al.,* 1998).

A recent study conducted at McNary Dam in 2002 showed no increase in descaling and injury for spring Chinook released in gatewells under a range of turbine operations up to the maximum turbine discharge (Absolon *et al*, 2003). These studies also indicated that fish exited gatewells faster under high flow conditions, which may be a benefit. Long-term effects related to physiological condition and chronic stress impacts were not evaluated. It should be noted that while the gatewells at John Day are different than the gatewells at McNary, higher gatewell flows at John Day Dam unexpectedly contributed to > 20% mortality in Chinook during development of the extended length screens (Brege *et al, 2001*) in units with unmodified vertical barrier screens.

Steelhead gatewell descaling information is limited for high turbine discharges. A 1992 turbine diversion screen evaluation comparing steelhead descaling at high and low turbine loads showed no significant difference. Steelhead passage through higher turbulence is expected to be the same or better than for yearling Chinook due to their stronger swimming ability providing better control in higher velocities. The opposite is true for sockeye because they are smaller, comparatively weaker swimmers and they incur higher descaling levels under existing operations. Increased velocities through the extended-length screens and higher turbulence in the gatewells may cause increased descaling levels. An in-season monitoring plan to detect increased fish injury in the gatewell environment will allow for in-season management decisions to minimize potential adverse effects.

- **Debris:** The VBSs are designed to evenly distribute flows to minimize fish impingement and descaling. Higher flow entering the gatewells draws in more debris that increases the risk of fish injury and damage to VBSs. Debris interacts with fish in two ways, by coming in contact with the fish as it tumbles in the turbulent flows and by impinging on the VBSs and causing increased velocities through the screens (and greater risk of fish impingement).

During the yearling Chinook and steelhead outmigration debris loads are generally light, with one or two occasions when spring runoff will flush debris into the river. Because McNary powerhouse operation draws in surface water containing debris, higher turbine loading will increase the debris volume entering gatewells. Adverse impacts on fish resulting from debris accumulations can be minimized by closely monitoring gatewell conditions (and fish condition) and quickly initiating debris removal actions. A monitoring program has been developed for this purpose (Monitoring Plan, 2004).

The debris detection and removal process poses some fish risk. From the time that monitoring results indicate a VBS must be cleaned until maintenance crews can do so, the unit load is reduced to the low end of the 1% range (40 MW). Generally fish survival is lower under this operation compared with the high end of the 1% range (Normandeau *et al,* 2003). The VBS cleaning process adds to the risk. The first step is to remove fish from the gatewell. Then the VBS is slowly raised and debris is washed off and back into the gatewell. While the VBS is cleaned, the unit continues to run at 40 MW to flush the debris out of the gatewell through the head gate slot. Because the unit is running, fish continue to be guided into the gatewell and, since the VBS is not in place, they may continue back into the turbine along with the debris where passage survival is lower that if they were diverted into the bypass system. Although no empirical data exists to quantify the effects of this operation, the cleaning frequency for VBSs will likely increase under the proposed higher turbine discharges.

d. Turbine Passage

Higher turbine discharges are not expected to alter the survival rate for fish passing through turbines sufficiently to be detected by current research methodology. Based on 2002 biological studies, the differences in yearling Chinook direct turbine survival at several operating points (including points outside of the 1% limit) were not significantly different (Normandeau *et al.,* 2003, Absolon *et al., 2003*). The highest mean passage survival trends occurred at an operation of 14,400 cfs above the 1% limit. Physical modeling results showed this operating point provided the best alignment of wicket gates to stay vanes and runner blades (termed an open geometry). The operation also provided the most uniform and equally distributed flows through the draft tubes. This latter effect is believed to offer the greatest potential to reduce fish contact with the turbine structures and, therefore, reduce the potential for injury and descaling.

Because the proposed operation is to lift the 1% rule without imposing a new biologically based operating limit, the units will likely be operated more often at the highest level (16,400) rather than at the open geometry operation (14,400 cfs). While the difference in yearling Chinook survival between the two operating levels was not significant, the survival rate for the 16,400 cfs operation was similar to the 12,200 cfs operation, the upper range for the 1% limit (Absolon et al., 2003). Therefore, it is unlikely that the yearling Chinook turbine passage survival rate will change if the units are operated over the 1% limit.

Currently, there are no empirical data available on direct turbine survival for steelhead at different turbine operating points. It is unknown if the small differences in turbine survival observed for yearling Chinook will apply to other species. However, based on the assumption that injuries resulting from the hydraulic forces in the turbine environment are a function of the surface area of the fish, smaller fish are expected to have higher turbine survival. This would suggest that wild steelhead may have a similar probability of injury to yearling Chinook and hatchery steelhead may be slightly lower. Regardless, the differences in turbine survival between existing and higher turbine discharges are expected to be relatively small and undetectable by current research methodologies.

e. Tailrace Egress

Tailrace hydraulic conditions are a function of turbine discharge and spillway operations. Poor tailrace conditions affect the egress of juvenile fish passing through all routes at McNary Dam, including spillways, turbines and the juvenile fish bypass system. Delays in the tailrace increase the risk of predation and exposure to high TDG levels

Increased turbine discharges are expected to alter the tailrace environment. Hydraulic modeling data indicate that higher turbine discharges may provide better egress conditions downstream of the powerhouse by forcing more flow through the tailrace. This is expected to reduce slow moving eddies, thus enabling fish to move downstream through the tailrace more directly and rapidly after passing through the powerhouse. This may reduce the risk of tailrace predation by eliminating areas that piscivorous fish occupy and decreasing exposure to predators (bird and fish), and therefore may increase powerhouse survival.

f. Project Survival

Limited survival data for yearling Chinook at McNary Dam indicate that spill survival (98%) is higher than survival through the turbines (87%) or the juvenile fish bypass system (93%) (NMFS, 2000 Biological Opinion, Appendix D and Route Specific Survival Estimates compiled by the 2003 Joint Data Review Team). Because route specific survival data for steelhead at McNary is limited, yearling Chinook data was used as a surrogate for steelhead (NMFS, personal communication)

To assess the effects of reduced involuntary spill levels on project survival, existing route specific survival estimates were modeled (Table 5).

Table 5. Route Specific Survival at McNary for Spring Chinook and Steelhead

Route Specific Survival	Yearling Chinook and Steelhead
Turbine Survival	0.87
Spill Survival	0.98
Bypass Survival	0.93
FGE	0.87
Diel Percentage	0.5

The seasonal average of 2.5% reduction in involuntary daytime spill is expected to decrease yearling Chinook and steelhead project survival by approximately 0.18% over the spring out migration (Table 6).

Table 6. Project Survival Estimate for the Proposed Spring Turbine Operation for 2004.

Estimated Change in Juvenile Project Survival at McNary 2004 Under Different Flows Conditions

		Change in Involuntary Spill	
Range of Flows at McNary	Percent of Spring Season	Change in SPE	Change in Project Survival
185 kcfs to 230 kcfs	80%	0%	0.0%
230 kcfs to 260 kcfs	17.5%	-18.0%	-0.8%
260 kcfs to 280 kcfs	2.5%	-20.2%	-1.8%
Weighted Mean		-3.6%	-0.20%

It is not known to what degree increased flows through the fish guidance screens, gatewells, turbines, or tailrace may change the project survival. The estimated project survival reductions were based on an assumption that increased turbine discharge does not alter fish survival through turbines, the juvenile fish bypass system and tailrace environment.

g. Other Effects

Adult fish bound for the Umatilla basin have been documented passing McNary dam before falling back to the Umatilla River. Based on radio telemetry data, about 45% of the adult Chinook spawning in the Umatilla River between 1996 and 2002 passed McNary Dam before falling back to the Umatilla (ICFWU, personal communication). Currently, the route of downstream passage with the highest survival for adult fish is assumed to be through spill. Because adult fish usually migrate during the day, a reduction in daytime involuntary spill may result in more adult fish falling back through the powerhouse, and increase the percentage of adults passing through the turbine environment. Based on the results of a 2003 balloon tag pilot study, direct impacts of turbine passage are expected to more detrimental to adult fish when compared to juveniles (Normandeau and Mid Columbia Consultant, 2003). Approximately 10% of the adult fish recovered in the 2002 pilot study were injured; most of the injuries were attributed to mechanical impact. It is unknown if the impact injuries would be reduced under the proposed operations. Under the turbine discharges of 14,400 cfs (above the 1% limit) the alignment of wicket gates to stay vanes and runner blades provide the most open configuration and the most uniform and equally distributed flows through the draft tubes. This may reduce fish contact with the turbine structures and reduce the potential for injury.

5. Physical Effects

a. Water Temperature
Water temperature drives many biological processes in fish. Their physiology and performance is compromised by chronic exposure to thermal stress, leading to increased susceptibility to disease with increases in water temperature. As a result, indirect temperature effects may cause substantial extra and delayed mortality to smolts passing through the juvenile bypass and collection facilities. At this time, the turbine operations outside 1% is being evaluated for the spring migration, which ends when the river is no longer spring like and exceeds 62^{o}F (17^{o}C) water temperatures (Water Management Plan, 2003), so no temperature-related adverse effects to fish are expected.

b. Total Dissolved Gas
As described in Section 4 above, involuntary spill will be reduced under the proposed action.

7. Summary of Potential Effects of the Proposed Operation
The BPA proposal to operate the McNary turbines outside the current 1% guidelines will result in higher powerhouse discharge than the existing turbine operation. Increased flow from the higher discharge will affect fish passage and survival for the following reasons:

- Decreased involuntary spill will route a seasonal average of 3.6% of the juvenile fish away from the spillway and through passage routes with lower levels of survival resulting in a small reduction in project survival (0.2% for yearling Chinook and steelhead) over the spring outmigration.
- Depending on the specific turbine operating point, higher discharges may improve turbine passage survival by providing more open turbine geometry and more uniform flows through the draft tubes, which reduces the likelihood of impact injuries to fish.
- Increasing the flow velocities through the extended-length screens may increase the frequency of fish impingement and injury by an unknown amount as they are guided into the gatewells.
- Increased turbulence and debris in the gatewells may increase the fish injury rate. However, increased flows in the gatewell generally results in fish exiting the gatewells faster which may reduce exposure to turbulent conditions A comprehensive in-season monitoring program will reduce the risk-associated injuries associated with the gatewell environment.
- Improved hydraulic conditions of the tailrace may reduce the risk of predation on in-river migrants.

The change of the turbine operation to include the above 1% peak of efficiency may reduce McNary project passage survival for listed Snake River spring/summer Chinook and steelhead, and UCR steelhead by approximately 0.2%, due to the redirection of daytime involuntary spill to the powerhouse. A comprehensive in-season monitoring plan sufficient to detect increased fish injury in the gatewell environment, thus allowing for in-season management decisions (i.e., reinstate the 1% limit) to minimize potential adverse effects (Monitoring Plan, 2004). All monitoring information and estimates of fish effects, as well as information from related studies, will be documented in a summary report at the end of the season.

7. References

Absolon, R.F., M.B. Eppard, B.P. Sandford, G.A. Axel, E.E, Hockersmith and J.W Ferguson. 2003. Effects of turbine operations at two different discharge levels on survival and condition of yearling Chinook at McNary Dam, 2002. NMFS for USACE, Contract No. W68SBV20655422, Walla Walla, Washington.

Bell, Milo C., 1981. Updated Compendium on the Success of Passage of Small Fish Through Turbines. Contract No. DACW-68-76-C-0254, U.S. Army Corps of Engineers.

Brege, D.A., R.F. Absolon, B.P. Sandford, and D.B. Dey. 1998. Studies to evaluate the effectiveness of vertical Barrier screens and outlet flow-control devices at McNary Dam, 1997. NMFS for USACE, Walla Walla, Washington.

Brege, D.A., et al., 2001. Evaluation of extended length bar screens at the John Day Dam, 1999. NMFS for the USACE, Portland, Oregon.

Joint Data Review Team. Results from agreed upon model number for passage specific survival at McNary Dam. Meeting held at NOAA Fisheries, December 2003.

McComas, R. Lynn, Dean A. Brege, William D. Muir, Benjamin P. Sandford, and Douglas B. Dey. 19932. Studies to Determine the Effectiveness of Extended-Length Submersible Bar Screens at McNary Dam, 1992. NMFS for USACE, Walla Walla, Washington.

NMFS. 2000. Endangered Species Act, Section 7 Consultation, Biological Opinion Reinitiaton of Consultation on the operation of the Federal Columbia River Power System, National: Biological Effects Analysis and SIMPAS Model Documentation.

Normandeau Associates, Inc., J.R. Skalski, and Mid Columbia Consulting, Inc. 2003. Survival/Condition of Chinook salmon smolts under different turbine operations at McNary Dam, Columbia River. USACE, Contract No. DACW68-02-D-002, Walla Walla, Washington.

Normandeau Associates, Inc., and Mid Columbia Consulting, Inc. 2003. Feasibility of Estimating Passage Survival of Adult Salmonids Using the HI-Z Tag-Recapture Technique. USACE, Contract No. DACW68-02-D-002, Walla Walla, Washington.

Skalski, John R., Dilip Mathur, Paul G. Heisey, 2002. Effects of Turbine Operating Efficiency on Smolt Passage Survival. North American Journal of Fisheries Management 22:1193-1200, 2002.

USACE. 2004, Monitoring plan for the operation of McNary Dam above the 1% peak of efficiency turbine operation ranges. Walla Walla, Washington.

Water Management Plan (Final – October 1, 2002), 2003. Technical Management Team. U.S. Army Corps of Engineers, Northwestern Division Webpage (TMT). Document prepared as part of the implementation planning process as outlined in the 2000 NOAA and USFWS BiOps.